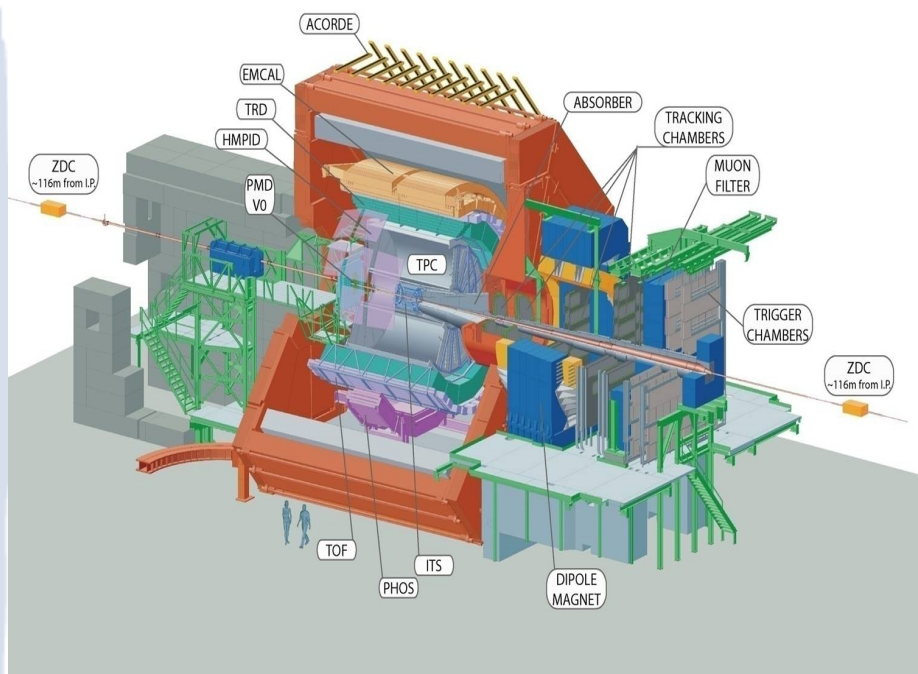


# J/ $\psi$ production in pp collisions with ALICE

Ionut Cristian Arsene  
for the ALICE Collaboration



FIAS Frankfurt Institute  
for Advanced Studies

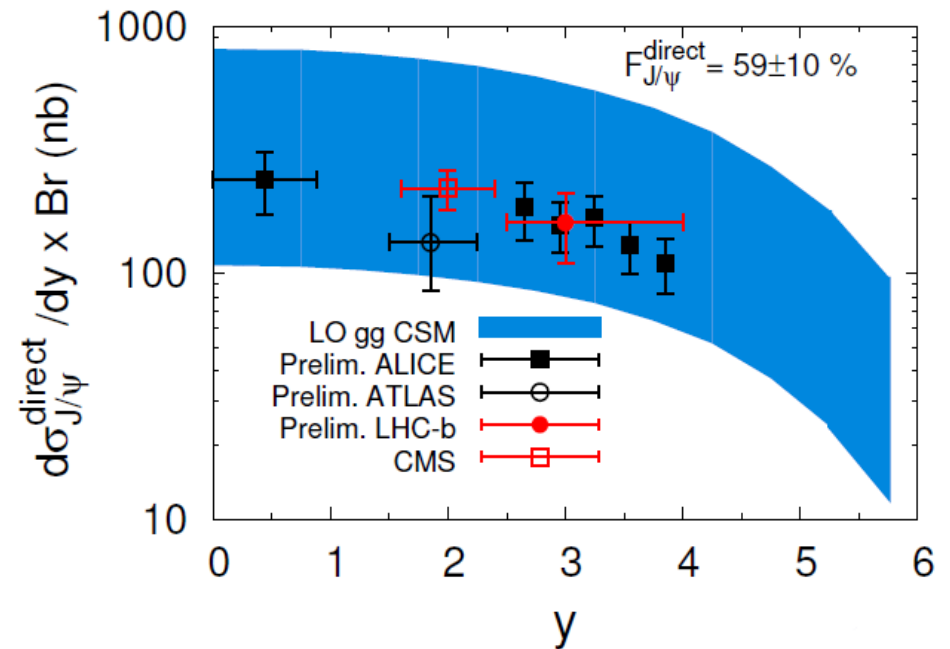
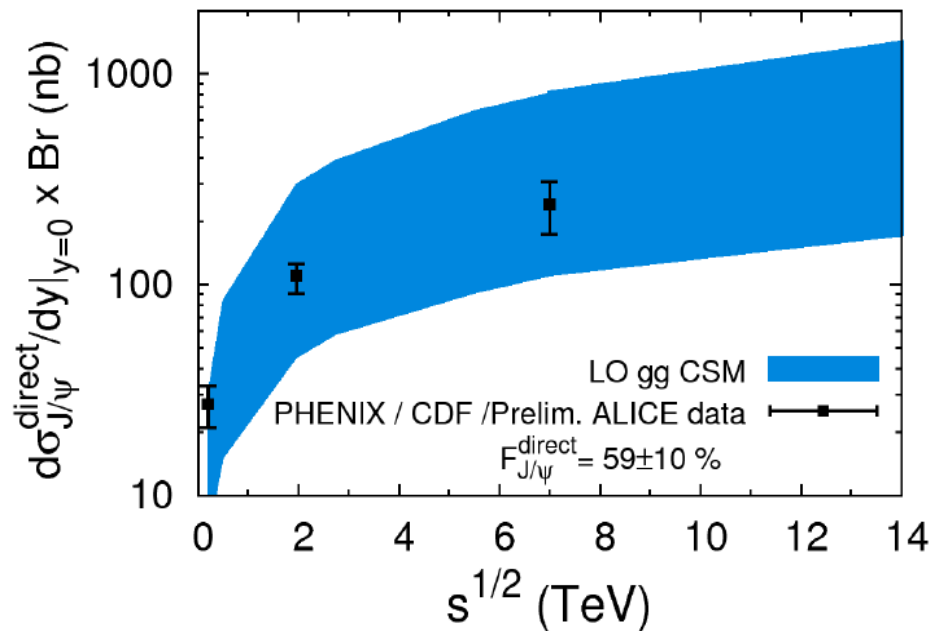


Quarkonium Production in Elementary and Heavy Ion Collisions,  
Brookhaven National Laboratory, June 9 2011

# Motivation

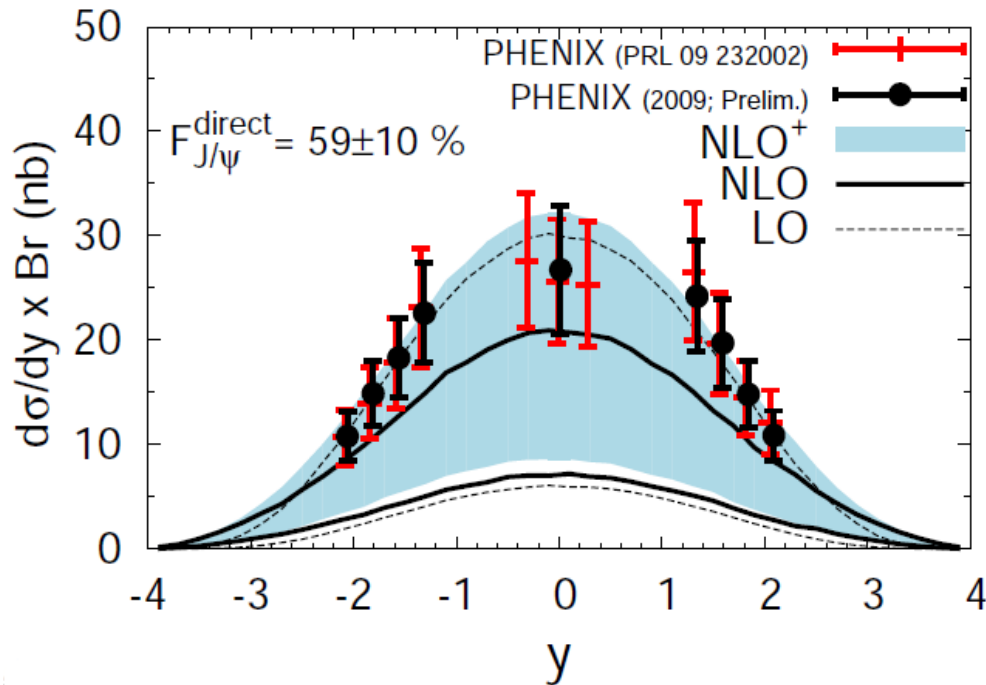
# Motivation

- ✓ Quarkonium production is an important observable in both elementary and heavy ion collisions.
- ✓ The production mechanisms in pp collisions are not fully understood but recent theoretical developments can account for the yields:

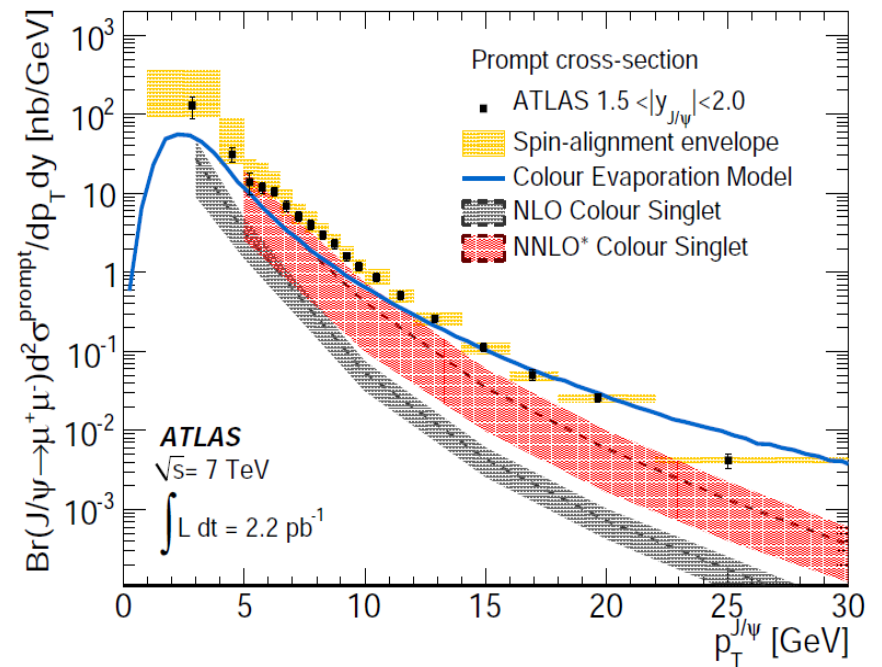


J.P.Lansberg, PoS(ICHEP 2010), 206

# Motivation



S.J.Brodsky, J.P.Lansberg, PRD81  
(2010) 051502



ATLAS Collaboration, arXiv:1104.3038

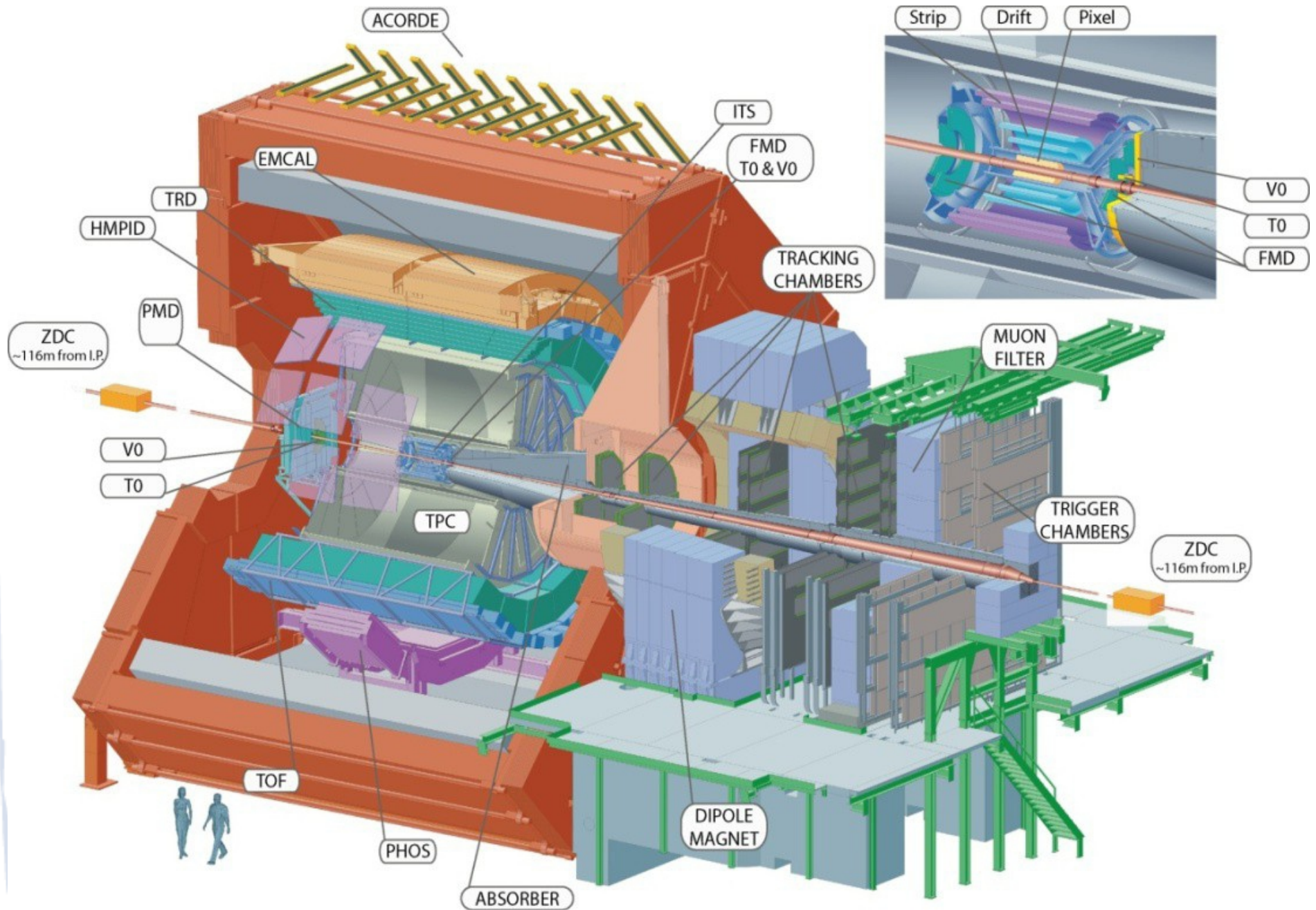
- ✓ Theoretical uncertainties are big
- ✓ NNLO\* corrections in the CSM model give a good description of the  $p_T$  spectrum at intermediate  $p_T$ .
- ✓ More observables from experiment should be employed to constrain theory?

# Experimentally accessible information

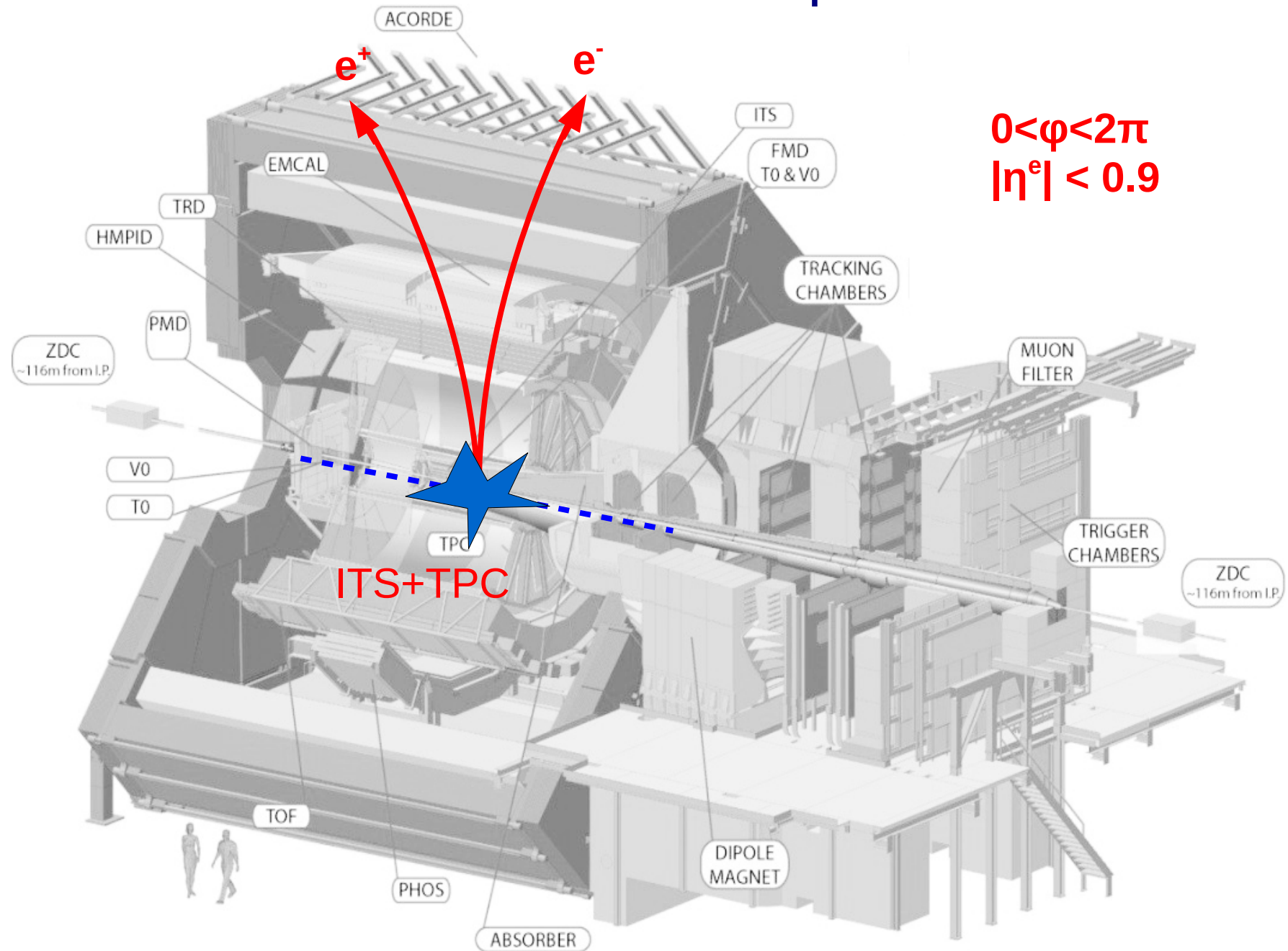
- ✓ Production rates (cross-section)
  - ✓ Inclusive and exclusive channels:
    - direct, feed-down from beauty and higher charmonium states
  - ✓ differential vs. rapidity, transverse momentum
- ✓ Correlations
  - ✓  $J/\psi$  correlations with hadrons, leptons, photons,
  - ✓ understand the production context
    - ✓ event multiplicity
    - ✓ underlying event, jet fragmentation cone
- ✓ Polarization measurements
  - ✓ Collins-Soper, Helicity

# Experimental setup

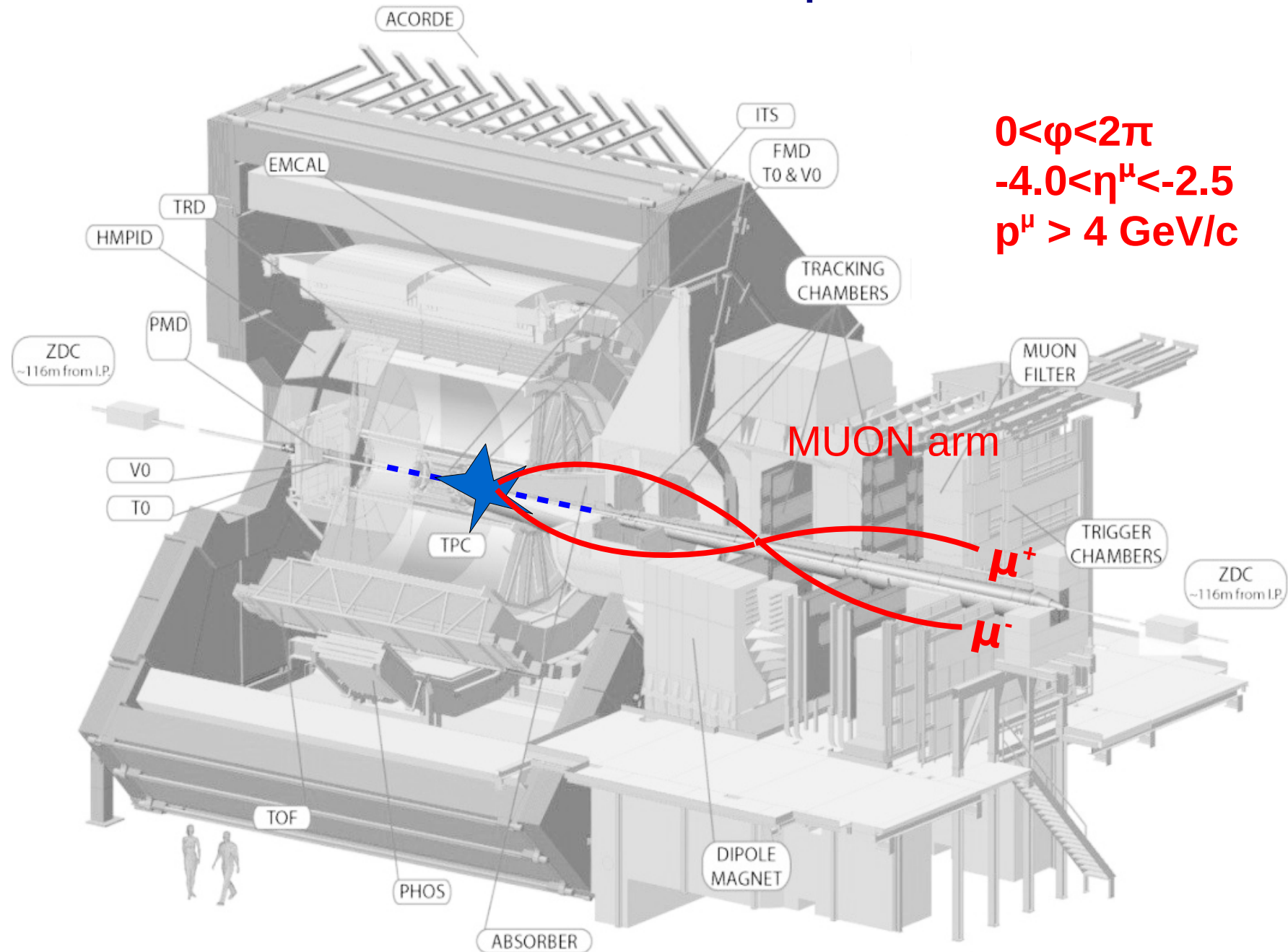
# ALICE setup



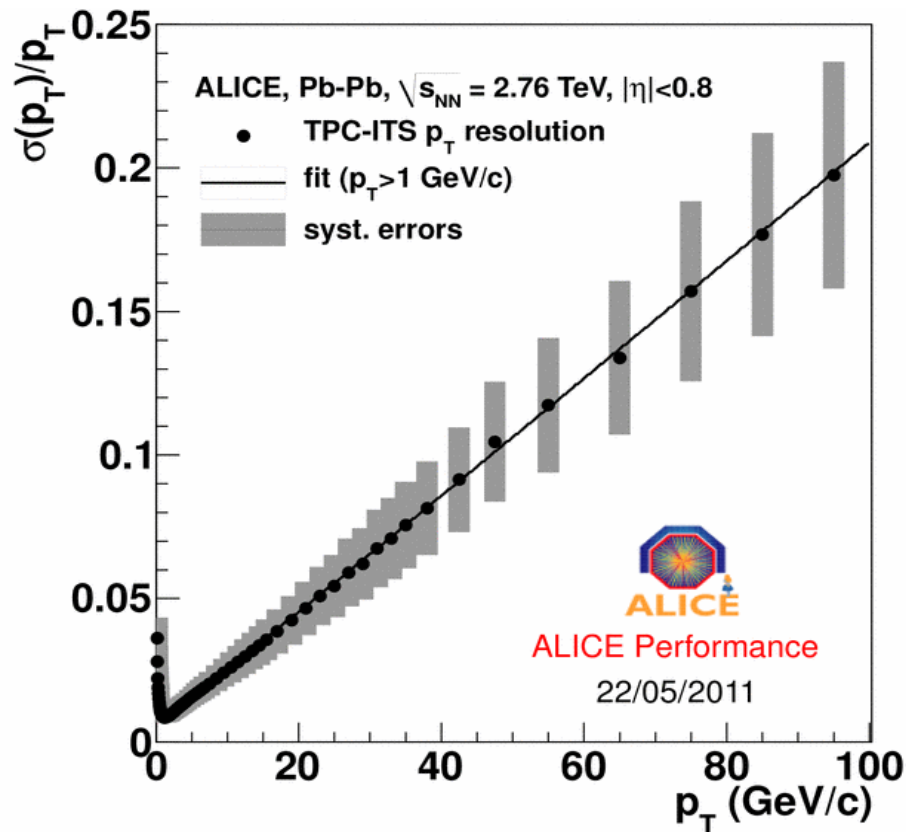
# ALICE setup



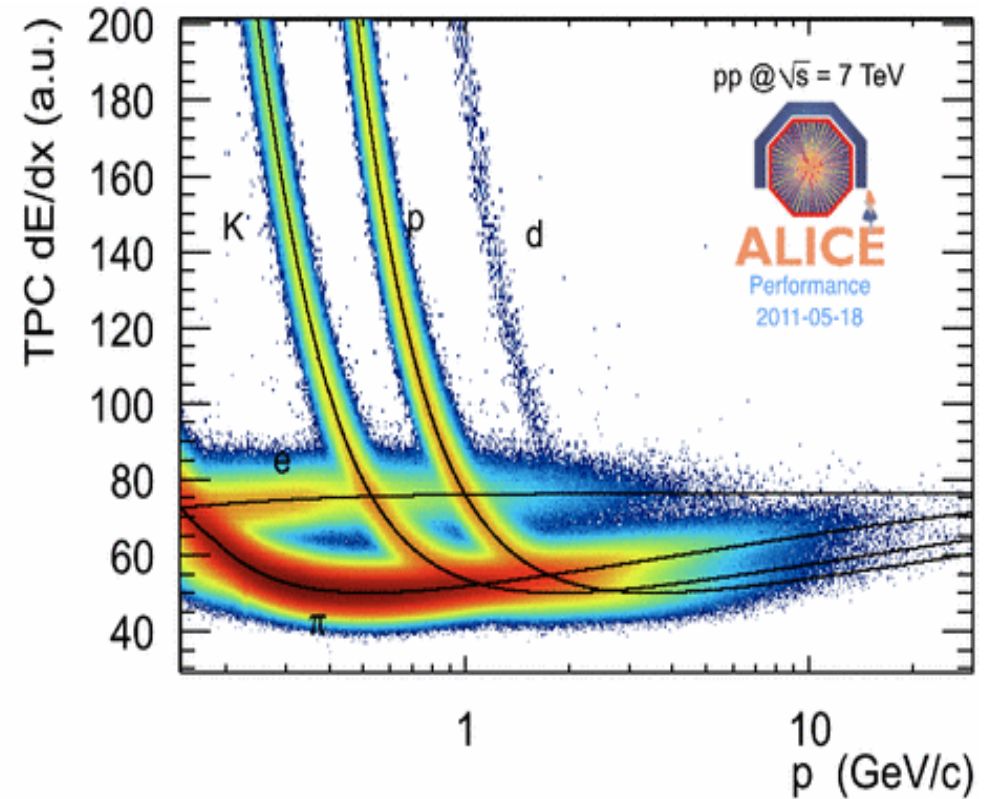
# ALICE setup



# Reconstruction in $J/\psi \rightarrow e^+e^-$ channel



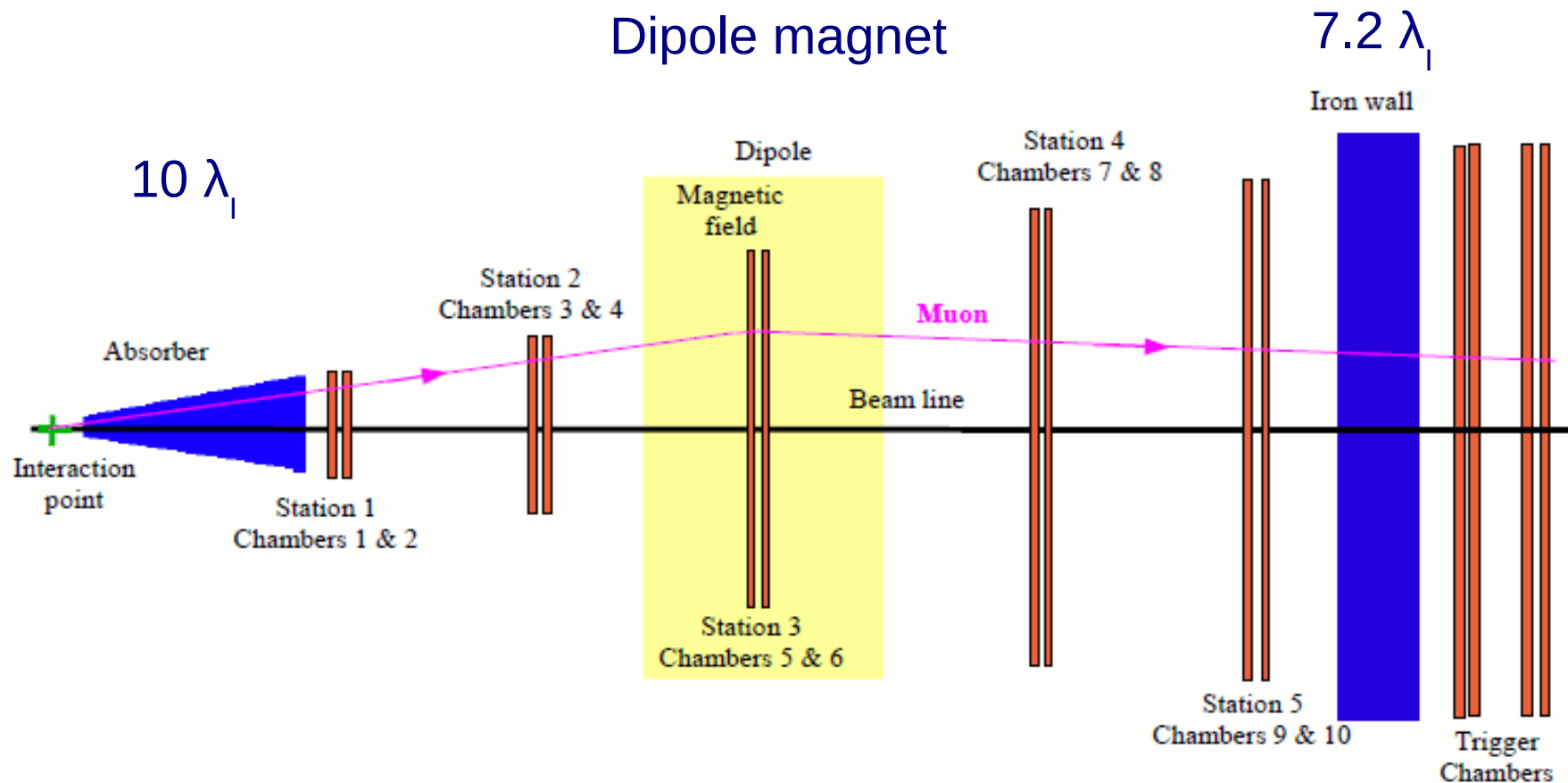
ALI-PERF-6582



Momentum resolution  $\sim 5\%$  at 20 GeV/c when combining ITS and TPC tracking

Particle identification done via specific energy loss ( $dE/dx$ ) allows the separation of electrons.

# Forward Muon Spectrometer



- ✓ Coverage:  $-4.0 < \eta < -2.5$  and  $p^\mu > 4.0$  GeV/c
- ✓ Dipole magnet and 5 tracking chambers used for momentum measurement
- ✓ Muons are isolated using hadron absorbers
- ✓ It can run at higher luminosities compared to the central rapidity detectors
- ✓ Allows measurement of heavy quarkonia ( $J/\psi$ ,  $\psi'$ ,  $Y$  family)

# Analysis

# Data

- ✓ Statistics:

- ✓ 2010 pp run at 7 TeV
- ✓ 2011 pp run at 2.76 TeV

Energy	$J/\psi \rightarrow \mu^+\mu^-$	$J/\psi \rightarrow e^+e^-$
7 TeV	15.6 nb <sup>-1</sup>	3.9 nb <sup>-1</sup>
2.76 TeV	20.2 nb <sup>-1</sup>	1.1 nb <sup>-1</sup>

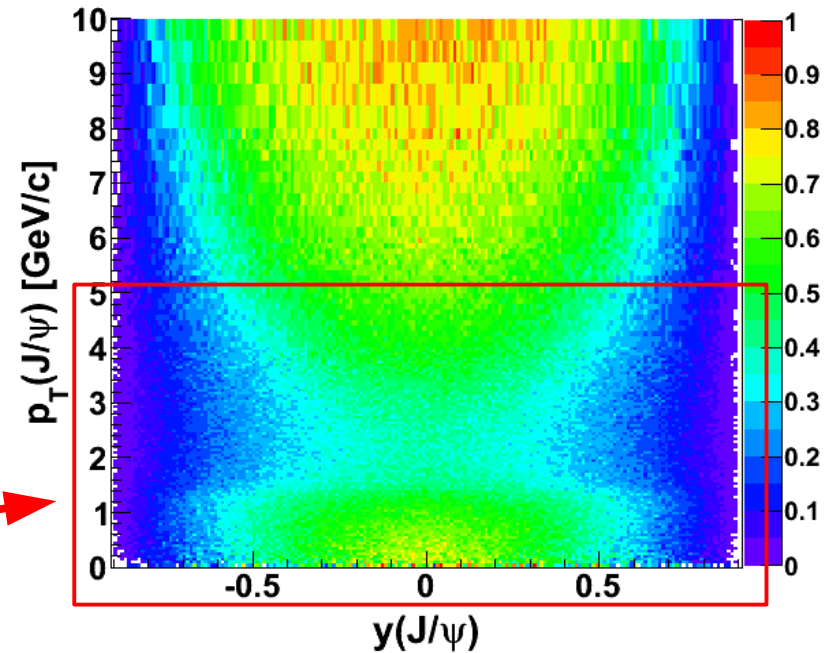
- ✓ Triggers:

- ✓ Minimum bias (inelastic trigger): Logic OR between our forward trigger detectors (VZERO) and a hit in the ITS
- ✓ At least one forward muon matched with the muon trigger system

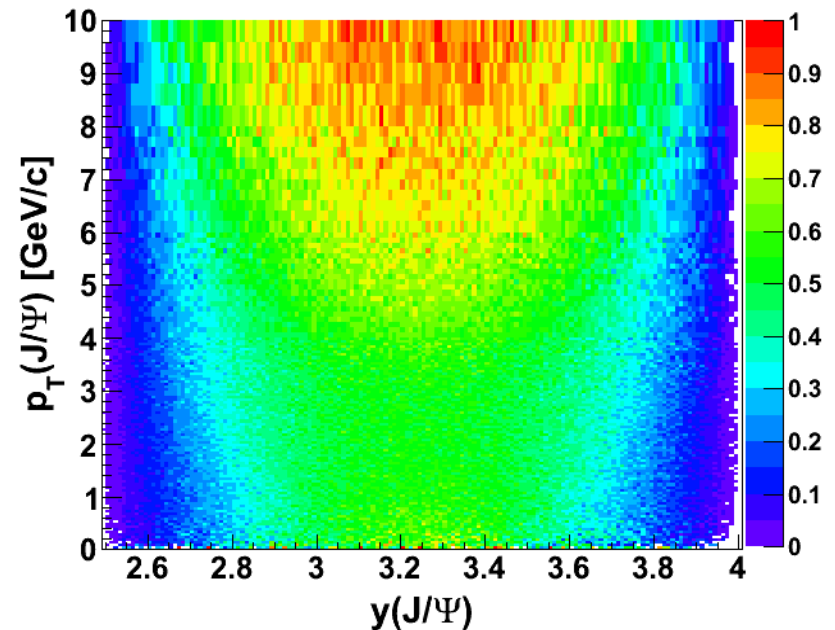
# Kinematical cuts

- ✓  $J/\psi \rightarrow e^+ + e^-$ 
  - ✓  $|\eta^e| < 0.9$
  - ✓  $p_T^e > 1.0 \text{ GeV}/c$
  - ✓  $|y^{J/\psi}| < 0.9$
  - ✓  $p_T^{J/\psi} > 0$

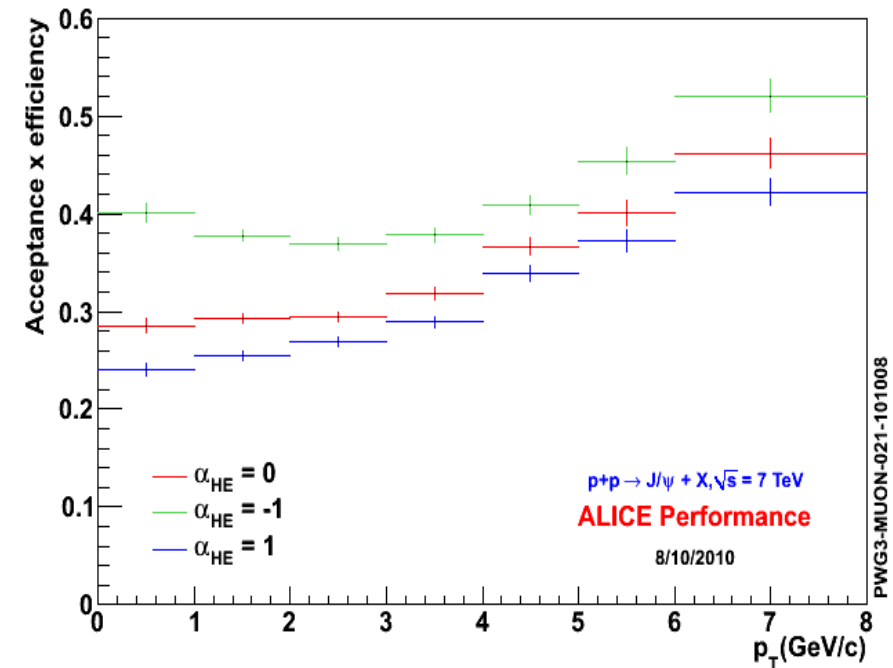
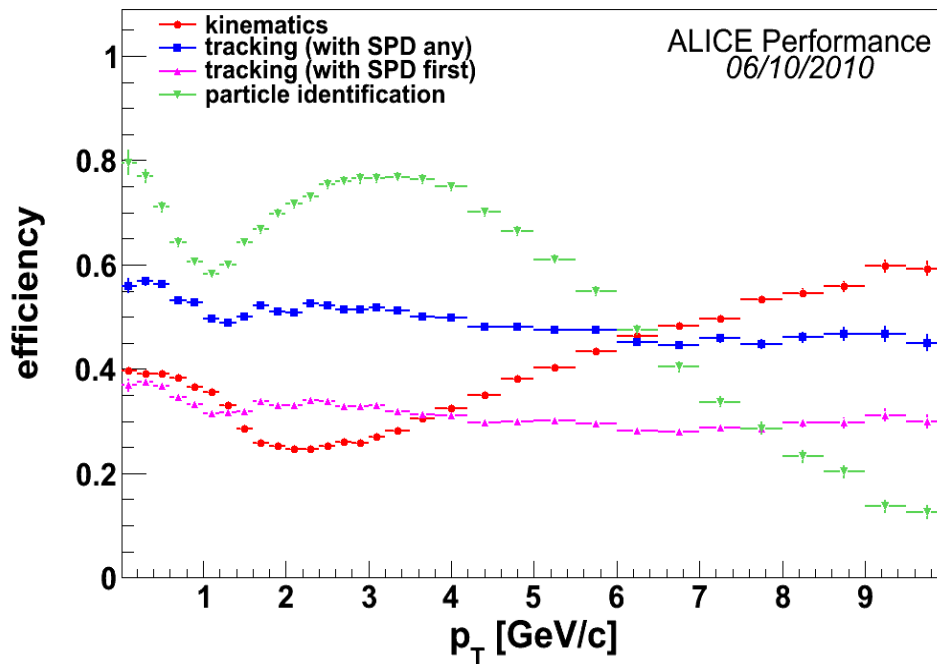
ALICE specific measurement  
at LHC



- ✓  $J/\psi \rightarrow \mu^+ + \mu^-$ 
  - ✓  $-4.0 < y^{J/\psi} < -2.5$
  - ✓  $p^\mu > 4.0 \text{ GeV}/c$



# Track candidate selection



## ➤ $J/\psi \rightarrow e^+e^-$ :

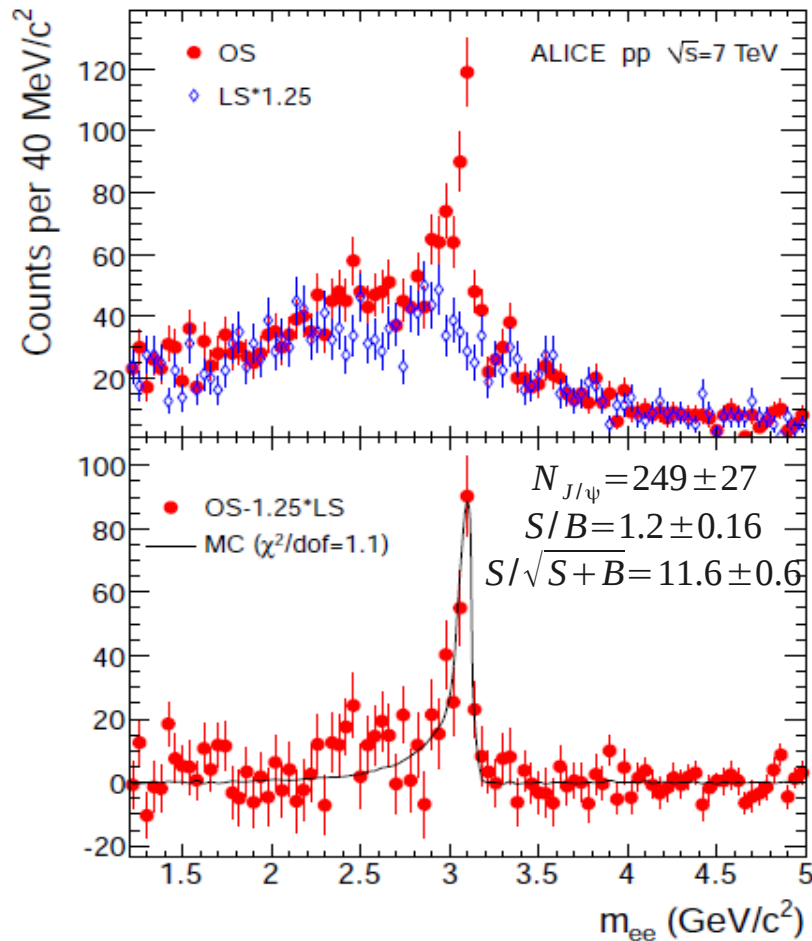
- Standard quality cuts on the ITS+TPC tracks
- Rejection of secondaries via tracking or DCA cuts
- Rejection of electrons from photon conversions in the detector material
- Electron selection done using the Bethe-Bloch curves for the specific energy loss in the TPC

## ➤ $J/\psi \rightarrow \mu^+\mu^-$ :

- Hadron rejection is done via the 2 absorbers
- Matching between the tracking and trigger stations is required for the muon tracks

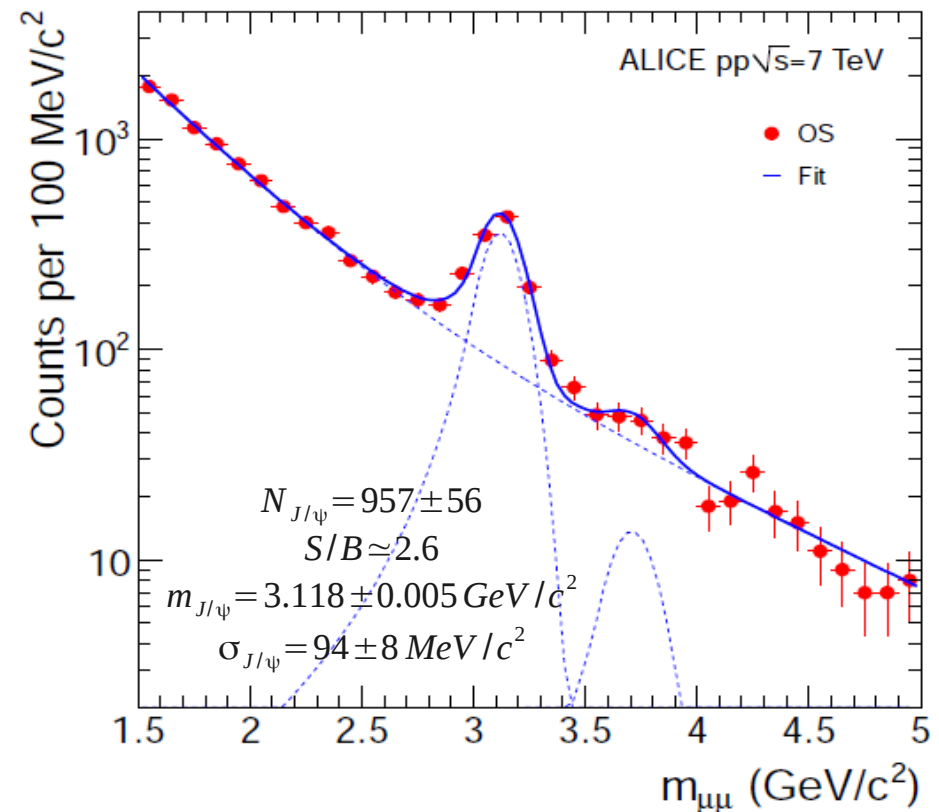
# Signal extraction (7TeV)

$J/\psi \rightarrow e^+ + e^-$



- Signal extracted using bin counting
- MC simulations describes well the signal shape

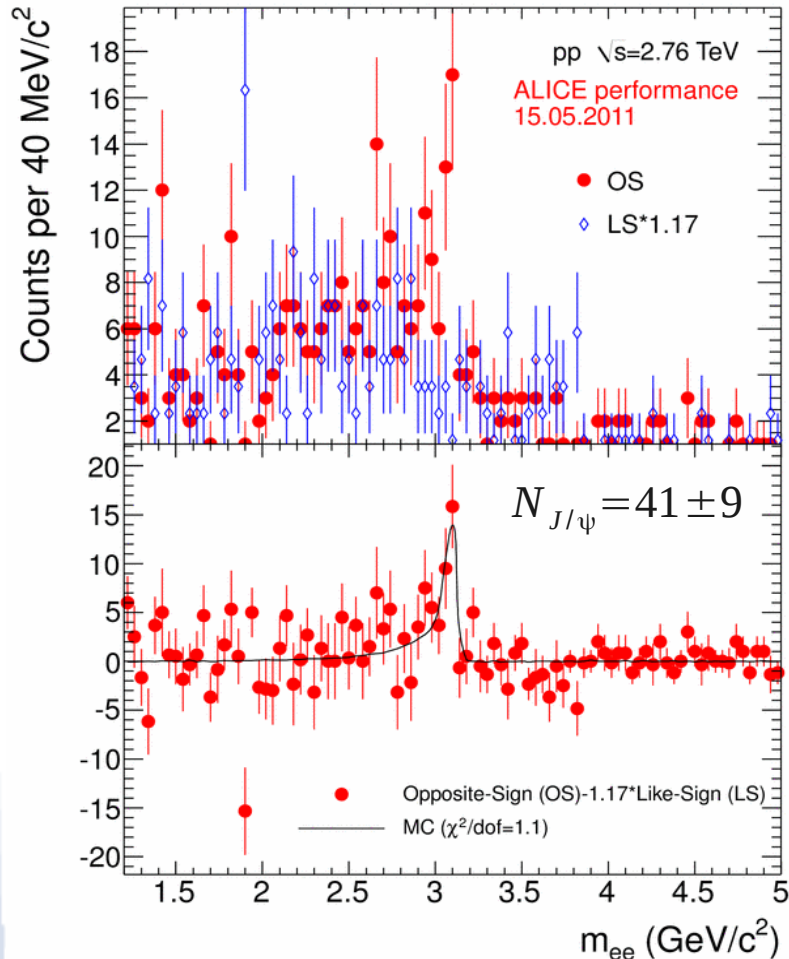
$J/\psi \rightarrow \mu^+ + \mu^-$



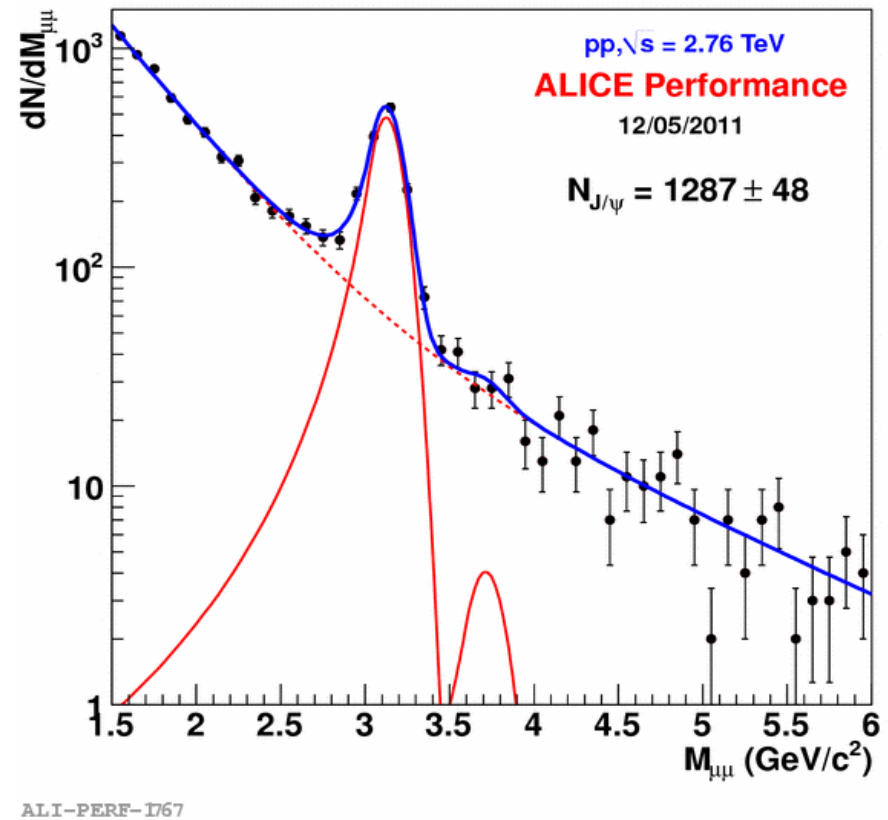
- Fits with Crystall-Ball functions describes well the dimuon invariant mass spectra.

# Signal extraction (2.76TeV)

$$J/\psi \rightarrow e^+ + e^-$$



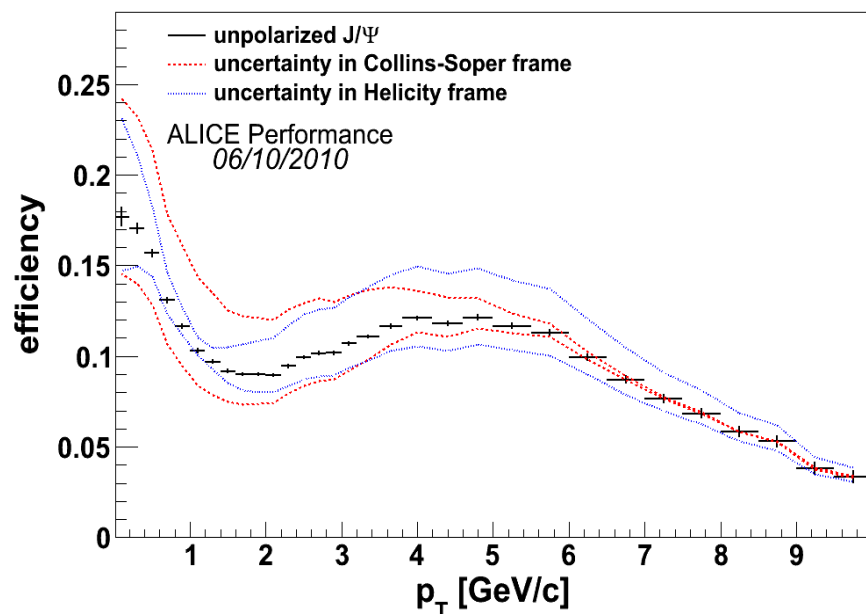
$$J/\psi \rightarrow \mu^+ + \mu^-$$



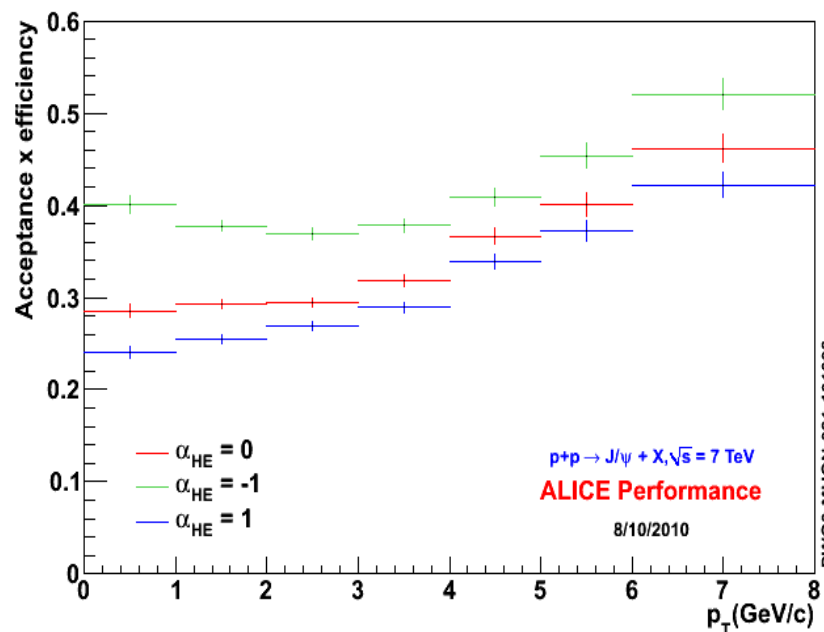
- Reference measurement for Pb-Pb collisions at 2.76 TeV/nucleon
- Signal extraction challenging but doable in the di-electron channel

# Efficiency and polarization systematics

$$J/\psi \rightarrow e^+ + e^-$$



$$J/\psi \rightarrow \mu^+ + \mu^-$$



- Unpolarized  $J/\psi$  assumption was used for the calculation of total efficiencies
- The impact of unknown polarization was calculated by assuming extreme polarization cases

# Systematic uncertainty

Channel	$e^+e^-$	$\mu^+\mu^-$
Signal extraction	8.5	7.5
Acceptance input	1	2.5
Trigger efficiency	-	4
Reconstruction efficiency	11	4
Trigger enhancement	-	3
Luminosity	8	8
Total systematic uncertainty	12.1	16

Polarization	$\lambda=-1$	$\lambda=+1$	$\lambda=-1$	$\lambda=+1$
Collins-Soper	+19	-13	+32	-16
Helicity	+21	-15	+24	-12

- Systematic error in both channels driven by the unknown polarization
- Other major systematic errors come from signal extraction and reconstruction efficiency (especially for the di-electron channel)

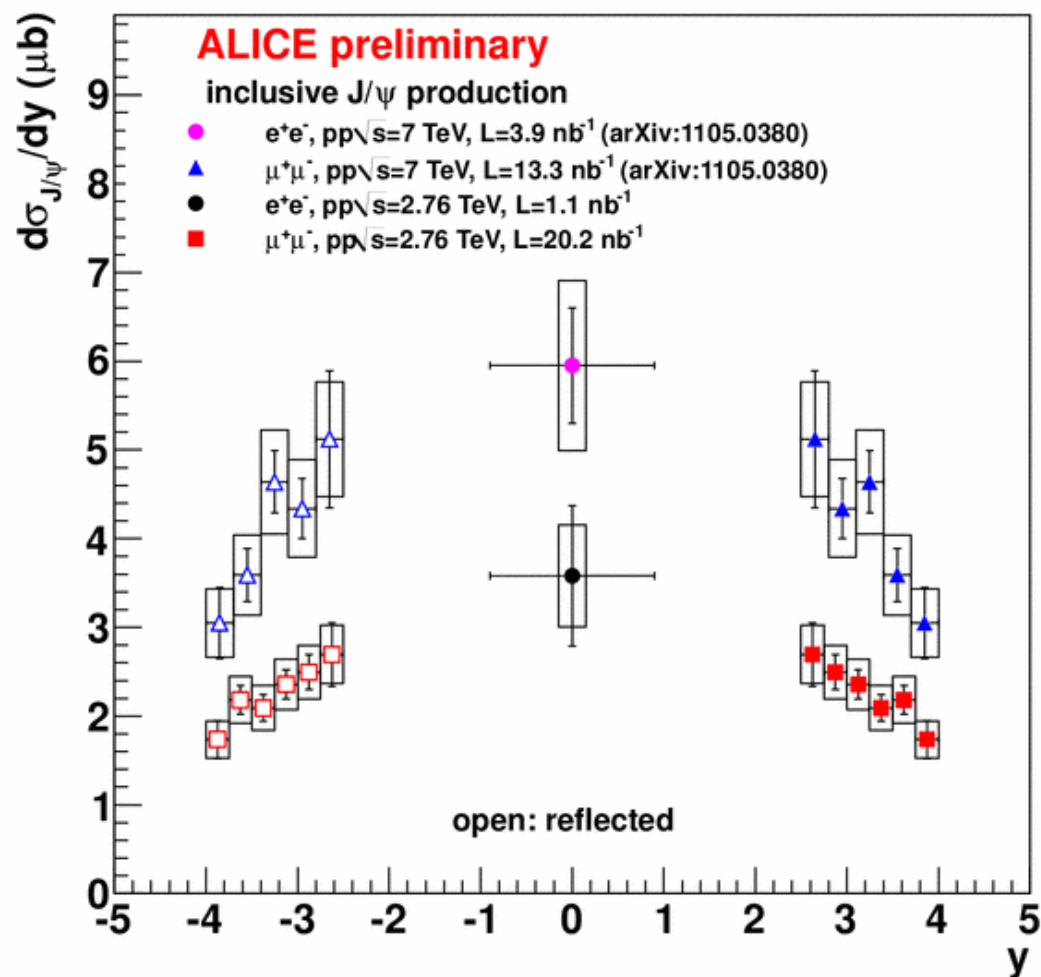
# Results

# Rapidity dependence of the inclusive cross-section

$$\sigma_{J/\psi} = \frac{N_{J/\psi}^{\text{cor}}}{BR(J/\psi \rightarrow \ell^+ \ell^-)} \times \frac{\sigma_{\text{MB}}}{N_{\text{MB}}}$$

$$\sigma_{\text{MB}}(2.76\text{TeV}) = 54.3 \pm 4.4 \text{ mb}$$

$$\sigma_{\text{MB}}(7\text{TeV}) = 62.3 \pm 5.0 \text{ mb}$$



ALI-PREL-1684

# Rapidity dependence of the inclusive cross-section

$$\sigma_{J/\psi} = \frac{N_{J/\psi}^{\text{cor}}}{BR(J/\psi \rightarrow \ell^+ \ell^-)} \times \frac{\sigma_{\text{MB}}}{N_{\text{MB}}}$$

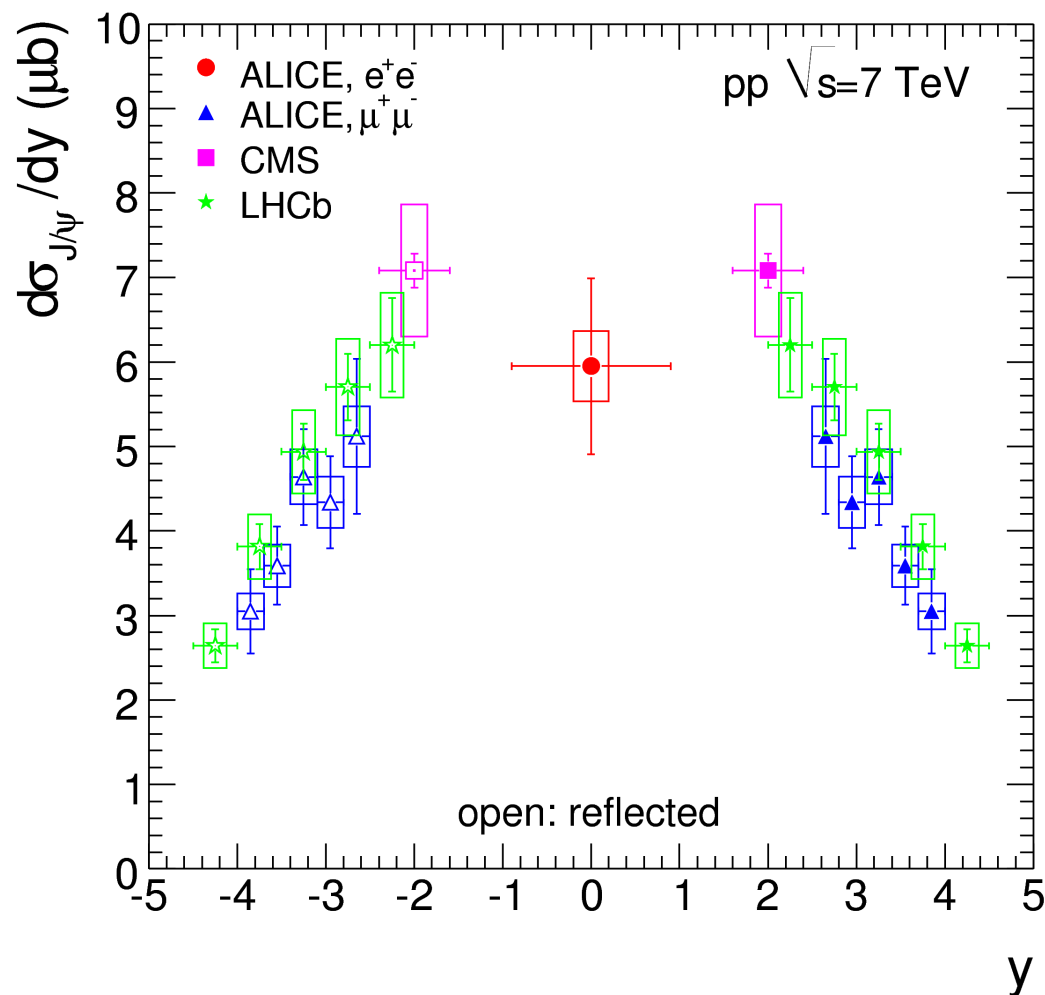
$$\sigma_{\text{MB}}(2.76\text{TeV}) = 54.3 \pm 4.4 \text{ mb}$$

$$\sigma_{\text{MB}}(7\text{TeV}) = 62.3 \pm 5.0 \text{ mb}$$

➤ Error bars are statistical and uncorrelated systematic errors added in quadrature.

Boxes are correlated error bars from luminosity.

➤ Comparison to CMS and LHCb shows agreement within error bars

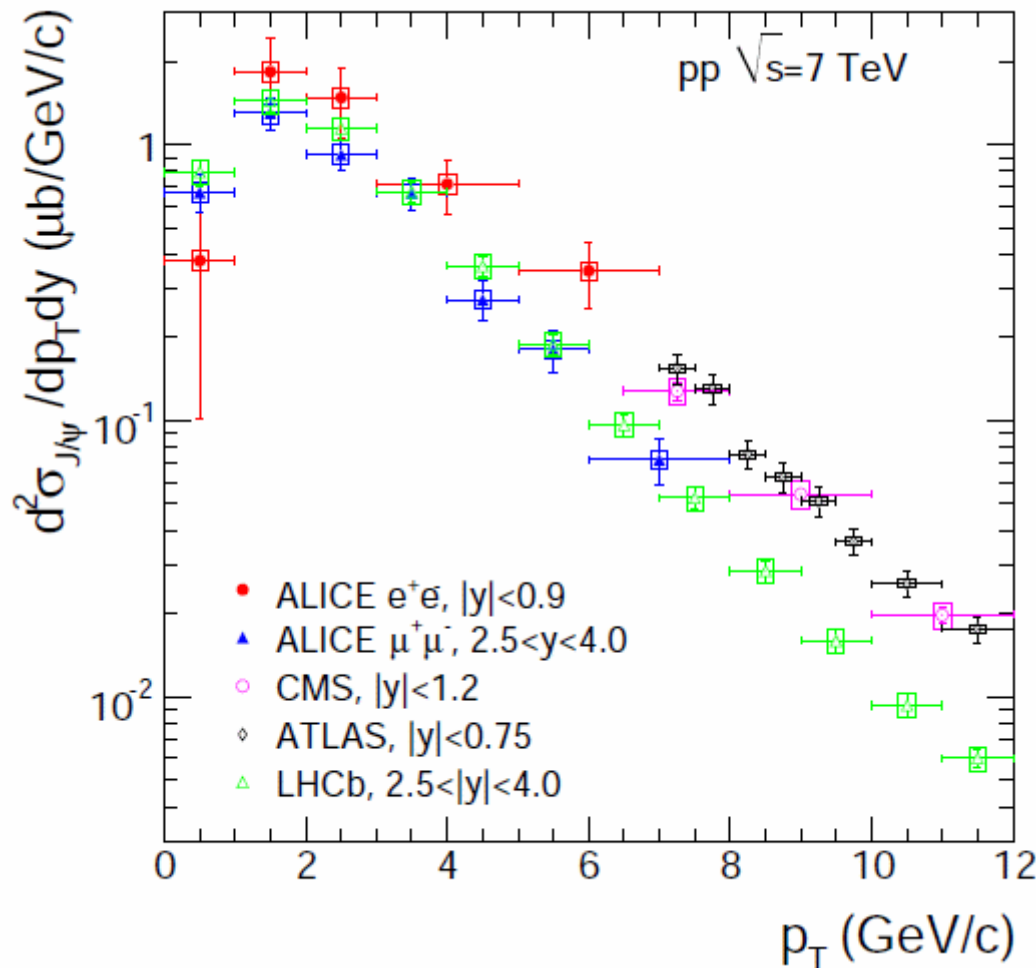


ALICE data: arXiv: 1105.0380

LHCb data: arXiv:1103.0423

CMS data: arXiv:1011.4193

# Pt dependence of the inclusive cross-section



- Good agreement between ALICE and LHCb for  $2.5<y<4.0$
- Pt spectrum at mid-rapidity is slightly harder than at forward rapidity
- At mid-rapidity, ALICE and CMS+ATLAS cover the full pt range

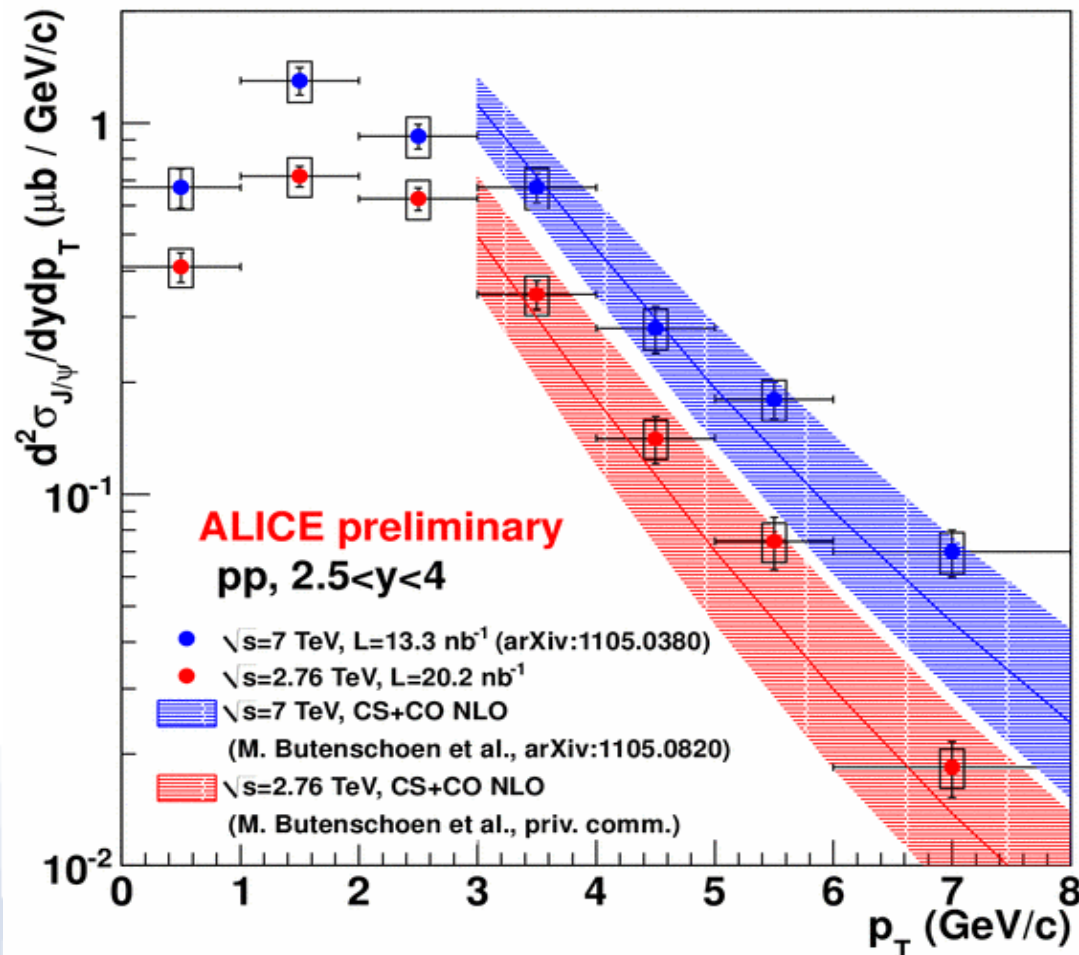
ALICE data: arXiv: 1105.0380

LHCb data: arXiv:1103.0423

CMS data: arXiv:1011.4193

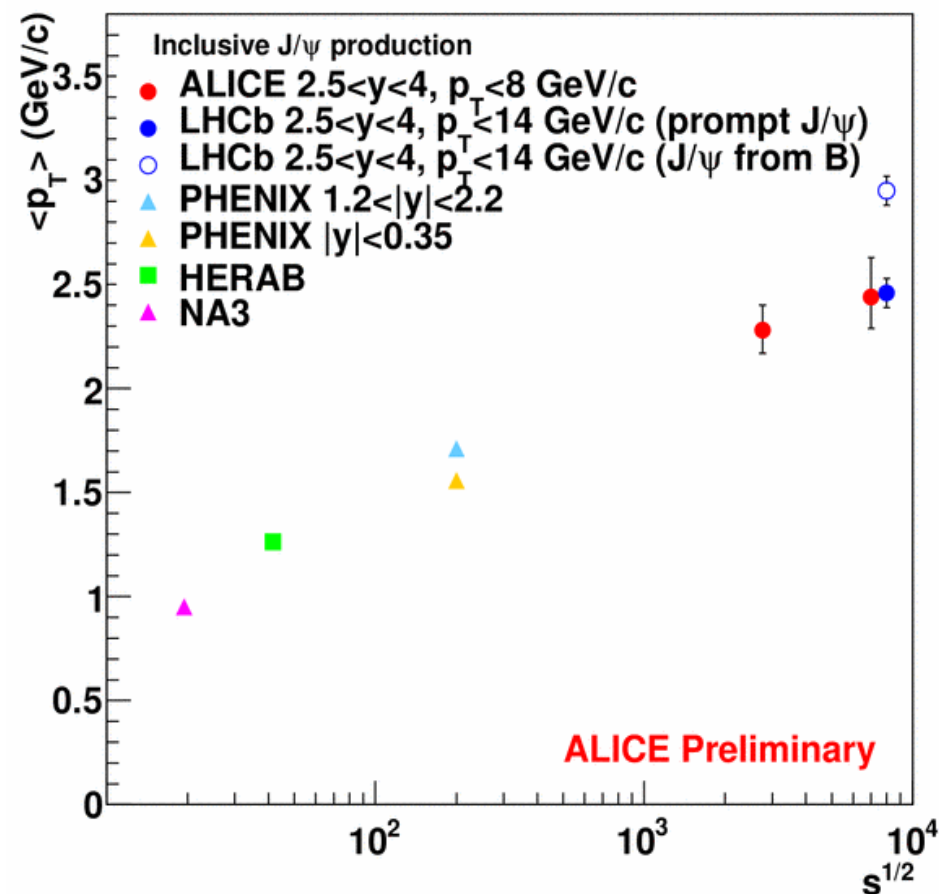
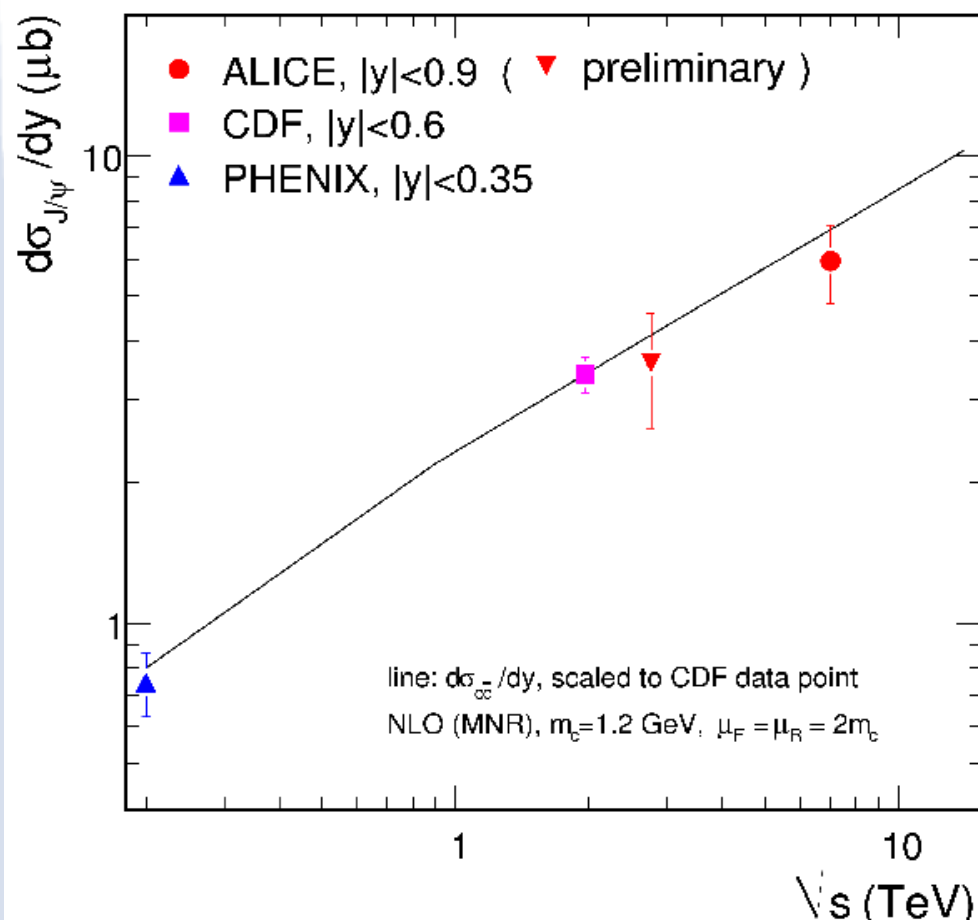
ATLAS data: arXiv: 1104.3038

# Pt dependence of the inclusive cross-section



- NLO calculations describe well pt spectra at forward rapidity
- Calculations reliable above  $p_T \sim 3$  GeV/c.

# Energy dependence



ALI-PREL-1687

ALICE data: arXiv: 1105.0380

CDF data PRD71 (2005) 032001

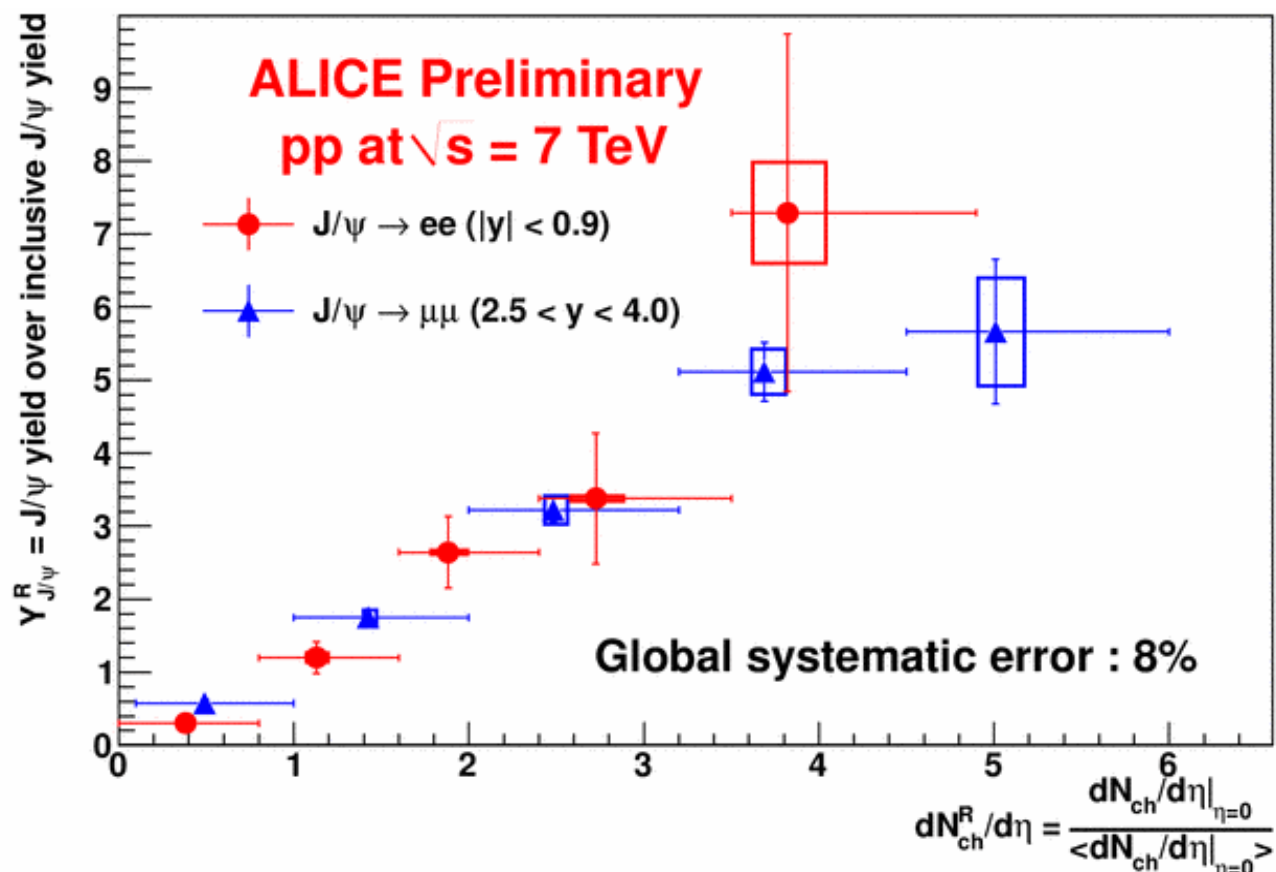
PHENIX data, PRL 98 (2007) 232002

M.Mangano et al., Nucl.Phys.B373 (1992) 295

Black line is a NLO calculation for the  $c\bar{c}$  cross-section scaled to the CDF point.

$J/\psi$  mean  $p_T$  grows roughly as  $\ln(s^{1/2})$

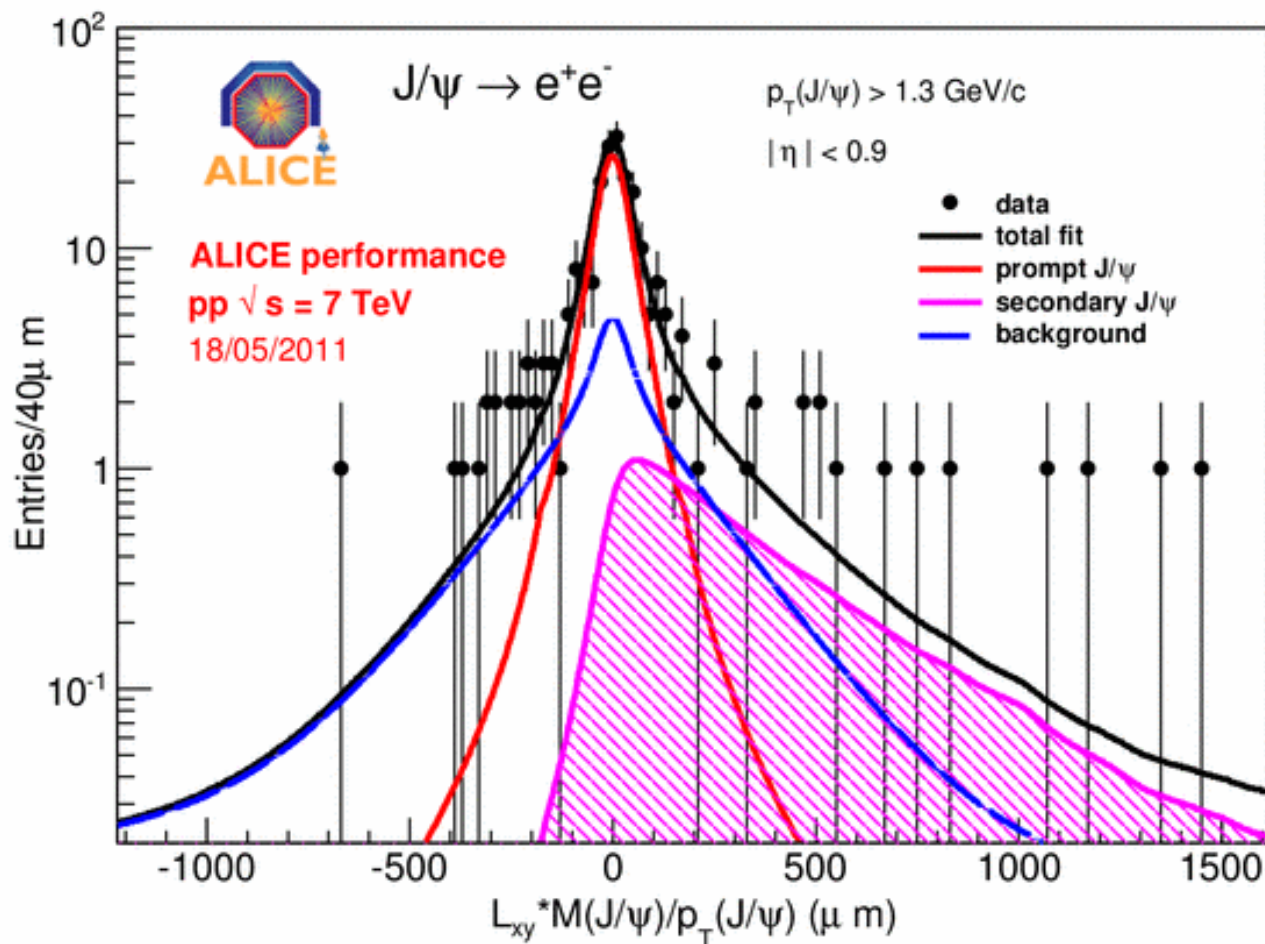
# J/ψ multiplicity dependence



ALI-PREL-4287

- J/ψ production is favored in high multiplicity events
  - Multi parton interactions?
  - Contributions from higher order pQCD diagrams?

# Feed-down from beauty hadrons

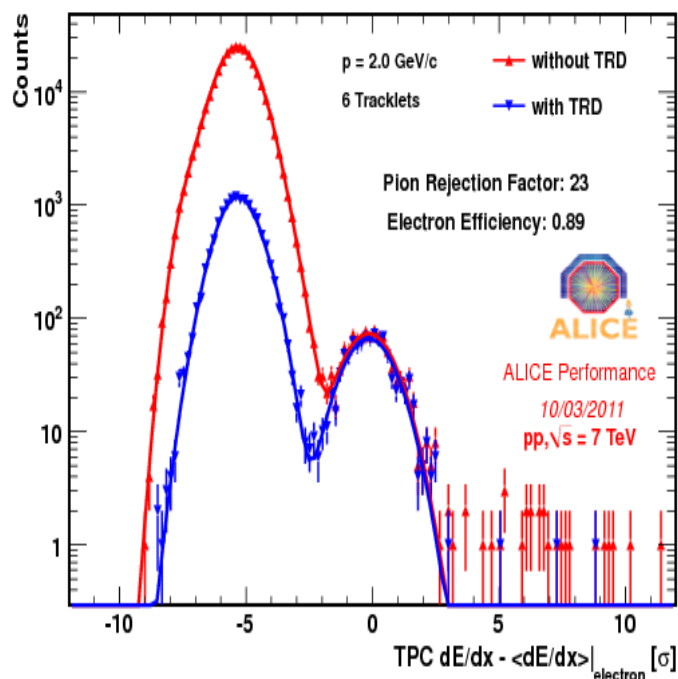


ALI-PERF-5143

- Not enough statistics with run 2010 data to separate feed down
- Higher luminosity and triggering will make the measurement possible in 2011

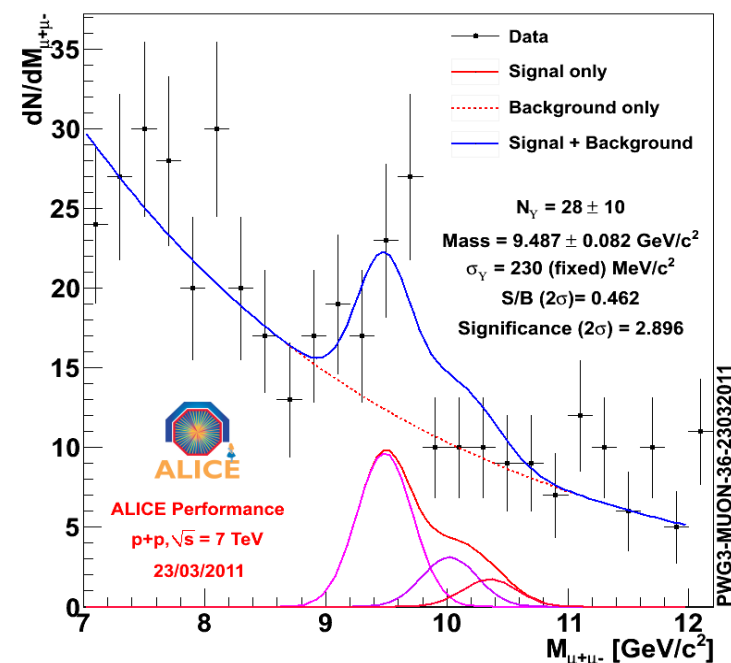
# Outlook

## Di-electron channel



- The extension of particle identification with the **TRD** and the **EMCAL** will increase the pt reach beyond 10 GeV/c.
- More statistics and high pt triggers will allow the measurement of
  - Beauty feed-down fraction,  $\psi(2S)$
  - Polarization,
  - $J/\psi$  correlations
  - $J/\psi$  in higher multiplicity events
  - $Y$  family

## Di-muon channel



- Running with higher luminosity will allow the measurement of
  - Polarization
  - $\psi(2S)$
  - $J/\psi$  in higher multiplicity events
  - $Y, Y', Y''$

# Conclusions

- ✓ The inclusive cross-section of  $J/\psi$  production in p+p collisions at 7 and 2.76 TeV recorded with ALICE was presented.
- ✓ Comparison with theory are underway. There is reasonable agreement in the  $3 < p_t < 8$  GeV/c region.
- ✓ The energy dependence of the mid-rapidity cross-section follows closely the behaviour of the  $c\bar{c}$  production cross-section calculated within NLO (MNR).
- ✓ We showed that the  $J/\psi$  production rate increases with the average event multiplicity.
- ✓ Increased statistics will allow new measurements like exclusive  $J/\psi$  production channels, higher charmonium states, polarization, correlations,  $\Upsilon$  family.